N, on the horizontal axis (x), then the result is a straight line, y=mx+b in the standard form. The quantity m is the slope and b is the intercept on the y-axis. The slope of the straight line is given by

$$Slope=\ln(RCliq/RCwtr) \tag{4}$$

Eq. (4) can be rewritten as follows:

$$RCliq=RCwtr\ e^{Slope} \tag{5}$$

In summary, the reflection coefficient for ultrasound striking a solid-liquid interface can be obtained by plotting the natural logarithm of the quantity (Vliq/Vwtr) versus the echo number and finding the slope of the line. The reflection coefficient RCliq is then determined from Eq. (5). The reflection coefficient RCwtr is determined from well-known formulations for the reflection coefficient, such as Krautkramer and Krautkramer (1990),

The above method uses the FFT amplitude at one frequency—one point on the amplitude-versus-frequency curve—but greater accuracy can be achieved by using several points as the following demonstrates. In this preferred application of the present invention the reflection coefficient does not depend upon frequency. While the peak of the FFT amplitude curve at a frequency fl has usually been chosen, it is by no means unique. The quantity V(**f2**, N) is defined as the FFT amplitude at frequency **f2** for echo N. Thus, it is another point of the EFT amplitude curve. Writing Eq. (3) for three frequencies **f1**, **f2**, and **f3** yields the following:

$$Ln(Vliq(f1,N)/Vwtr(f1,N))=N\ \ln(RCliq/RCwtr) \tag{6}$$

$$Ln(Vliq(f2,N)/Vwtr(f2,N))=N\ \ln(RCliq/RCwtr) \tag{7}$$

$$Ln(Vliq(f3,N)/Vwtr(f3,N)=N\ \ln(RCliq/RCwtr) \tag{8}$$

Adding the three equations together and realizing that the summation of logarithms is the same as products yields:

$Ln\ [Vliq(f1,N)Vliq(f2,N)Vliq(f3,N)/Vwtr(f1,N)Vwtr(f2,N)Vwtr(f3,N)]=3\ N\ \ln(RCliq/RCwtr)$ (9) This can be rewritten as:

$$Ln\ [Vliq(f1,N)Vliq(f2,N)Vliq(f3,N)/Vwtr(f1,N)Vwtr(f2,N)Vwtr(f3,N)]^{1/3}=N\ \ln(Rliq/Rwtr) \tag{10}$$

In this case, the quantity on the left side of Eq. (10) is plotted versus the echo number N, where the slope on this plot is determined. As before, the reflection coefficient is obtained using Eq. (4) and Eq. (5).

Eq.(5) shows that in order to determine the reflection coefficient for the liquid the theoretical formulation is required in order to determine the reflection coefficient for water for the perpendicular incidence and for incidence at 45°

A, Perpendicular Incidence

The formulation for the reflection coefficient for ultrasound traveling in a solid and striking the solid-liquid interface perpendicularly is given by:

$$RC=(Zliquid-Zsolid)/(Zliquid+Zsolid) \tag{11}$$

Z is the acoustic impedance defined as the density multiplied by the velocity of sound. For a calibration liquid, such as water and the known solid, the acoustic impedance of both the liquid and solid are known and so the RCwater can be determined.

From Eq. (5), the RCliquid can be determined from the reflection coefficient for water and the slope of the line on a plot, as has been discussed.

From the fluid specific reflection coefficient (RCfluid), computer **80** calculates the acoustic impedance of the fluid (Zfluid) according to Eq. (12).

$$Zliquid=Zsolid(1-RCliquid)/(1+RCliquid) \tag{12}$$

where Zsolid is the acoustic impedance of the solid member **40**. Eq. (12) was obtained by solving Eq. (11) for Zliquid.

The acoustic impedance of the fluid (Zliquidlis defined as follows:

$$\begin{aligned} Zliquid &= (\text{density of the liquid}) \\ &\quad (\text{velocity of sound in the liquid}) = \\ &= \rho c \end{aligned} \tag{13}$$

Where ρ is the density of the liquid and c is the speed of the sound in the liquid. A value has been obtained for the acoustic impedance of the liquid, but there are two unknowns: ρ and c. A second equation is obtained from the incidence at an angle of 45°, which is discussed next.

B. Incidence at 45° angle at solid-liquid interface

Eq. 5). shows that in order to determine the reflection coefficient for ultrasound striking the solid-liquid interface at 45°, a theoretical calculation of the reflection coefficient for water (or the calibration liquid) is needed and the "Slope" obtained from experimental measurements of multiple reflections, as discussed above. This procedure yields the experimental value of the reflection coefficient at 45°.

The objective of the measurements is to obtain values for the reflection coefficient at 90° (RC_{90}) and at 45° (RC_{45}). Since the theoretical equations include the density of the liquid and the velocity of sound in the liquid (which are unknown), as well as known properties of the solid and calibration liquid, the two unknown quantities can be determined. The following is a formulation for the reflection coefficient for SV shear waves striking a solid-liquid interface at an angle.

Referring now to FIG. **3**, FIG. **3** shows a shear wave striking a surface at an angle α_T and a reflected shear wave at angle α_T. For some incident angles α_T, a longitudinal wave is also produced in the solid at angle α_L and the restrictions will be discussed shortly. A longitudinal transmitted wave is also produced in the liquid at angle α. The longitudinal velocity in the solid is denoted by c_L and the shear wave velocity, by c_T. The velocity of sound in the liquid is given by c. The density of the solid is given by ρ_f and the density of the liquid by ρ.

As the angle α_T increases, the angle α_L also increases. The angle α_L cannot increase, obviously, beyond 90°. Thus, for some angle α_T, a longitudinal wave is simply not possible and does not exist. For a steel-water interface, this critical angle is about 33°. Beyond 33° the reflected longitudinal waves are not present. This is very advantageous because all of the reflected energy will be concentrated in the reflected shear wave. Calculations of the reflection coefficients for an incident angle α_T less than 33°, can be calculated according to the known formulas such as the one described by Krautkramer and Krautkramer (1990). However, for larger angles, the formulae are not provided but a method of derivation for obtaining such a value is described. Because the incident angle in these experiments is 45°, a derivation was carried out and the resulting reflection coefficient Rtt (using the notation of Krautkramer and Krautkramer) is given by:

$$Rtt=\{[(N1-N3)^2+N2^2]/[(N1+N3)^2+N2^2]\}^{0.5} \tag{14}$$

The parameter Con is defined as follows:

$$Con=(c_L/c_T)\sin\alpha_T \tag{15}$$

N1, **N2**, and **N3** are defined as follows:

$$N1=(c_T/c_L)^2[2Con(Con^2-1)^{0.5}]\sin 2\alpha_T \tag{16}$$